Cryomodule Production/Industrialization

0. NAPOLY (CEA)

PIP-II Technical Workshop

December 1st to 4th, 2020

A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/UKRI-STFC
- France/CEA, CNRS/IN2P3
- Poland/WUST

Introduction

This talk addresses the specific issue of **Cryomodule Series** production, with either in-house or industrial labour, in view of achieving the goals of:

- Product quality (performance)
- Productivity (throughput)

Product Quality

Assuming that the cryomodule design is sound, e.g. proven by upfront prototyping phase, the quality of the final product should derive from the following resources, made available for the purpose of the production phase :

1. valid procedures
2. proven tooling and equipment
3. skilled operators, mostly technicians

➢ one pre-series cryomodule is needed to assess the above pre-requisites.

To me, this is necessary and sufficient. However:

- for industrial labour, the training of operators requires special attention. It helps if the host institute has a say on the operator selection.
- Off-normal operations (e.g. repair operations) are **high-risk** deviations from the assembly process.

Productivity

Productivity is critical or not, depending on the number of cryomodules :

- for 10 CMs (e.g. LB650), a **2-week longer** throughput ends up with a **~5 months delay** for the delivery of CM#10: this has a significant impact (schedule, budget, etc.) on the downstream operations like testing and installation.

Throughput, including RF testing:

- in a chain of workstations, the production throughput is determined by the longest duration.
  - ➢ It is useful to balance the total workload as evenly as possible over workstations (cf. XFEL example in back-up material), respecting natural break-points (e.g. moving out of clean-room)
- with a single RF test bunker, the longest one is likely to be the duration of the cold RF tests, including CM installation, pumping, cool-down, warm-up, etc. Hence, it is important to develop a good understanding of these individual operations.

Productivity

Productivity depends mostly on project organization.

I would like to stress two key factors:

1. QA/QC methods:

- categorizing of non-conformities: PRODUCT, PROCESS, TOOLING
  - ➢ counting of manipulated parts per workstation, hints at the highest-risk operations, e.g. for XFEL, we had not anticipated that Warm Coupler assembly would generate, by far, the highest number of PRODUCT & PROCESS non-conformities (cf. back-up material).
- incoming inspection is the first line of defence against PRODUCT non-conformities
- QC on the floor is the first line of defence against PROCESS non-conformities
  - ➢ sufficient staffing and training of QC teams.

2. Reference 'senior' Engineers/Technicians with permanent presence/availability:

- on the floor(s), but not directly involved in the production to keep their free-standing view.

Productivity

Moving parts or Moving Team ?

- ‘Moving Parts’ favours the specialization of operators (a must for the clean-room).
- ‘Moving Team’ might favour their motivation

For XFEL, we moved parts, but we needed a few ‘flying operators’ with wide abilities to operate on several workstations.

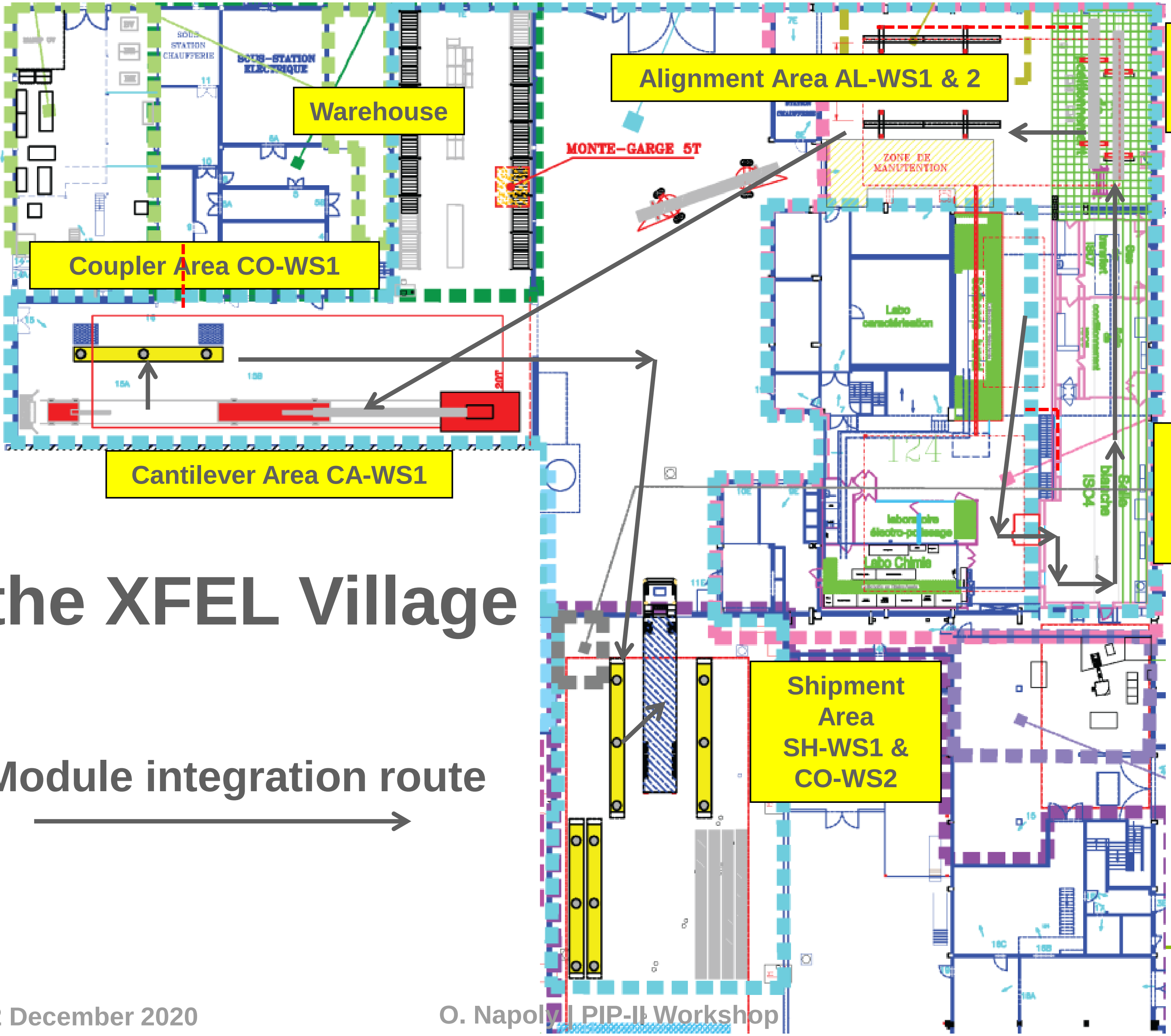
The success of the assembly team relies critically on:

- Expert vacuum technician in vacuum
- Expert technician in mechanics

and also: survey, welding, RF, cabling.

Back-up Material

Assembly Hall : Workstations



the XFEL Village

Module integration route

Organisation of Work Stations

The breakdown of the total assembly work over 7 workstations aims at:

- balancing almost equally the occupancy of each WS,
- bringing the longest WS occupancy below 5 days ($\rightarrow$ throughput)

1. **Clean Room Cold Coupler Area** (IS04-CC-WS)*2
   - Cold coupler assembly (x8)
   - Gate valve assembly
   - Leak check of cavity-coupler connection (+ RGA)
2. **Clean Room String Assembly Area** (ISO4-SA-WS)*2
   - String connections (8 cavities + 1 Qpole unit)
   - Leak check of string (+RGA) and N_2 venting
3. **Roll-out Area** (RO-WS)*2
   - 2 Ph-tube welding, NDT (VT, LT, RT)
   - HOM adjustment, magnetic shielding, T-sensors
   - Tuner assembly (x8), coupler 4K and 80 K shields
   - Cold-mass/string connection

# module components	# parts manipulated
~ 369	>1 075
~ 789	>2 096
~ 3 990	>4 238

Organisation of Work Stations

4. **Alignment Area** (AL-WS) *2
   - Cavity and quadrupole fine alignment (< 300 µm)
   - Welding of 8 mm LHe filling line (x9) (VT, PT, LT)
   - Tuner and piezo electric tests
5. **Cantilever Area** (CA-WS)*1
   - Welding of 4K-70 K shields, 4K-70 K super insulation
   - Cable routing and insulation, Qpole current lead
   - Insertion into vacuum vessel and cold mass alignment
6. **Coupler Area** (CO-WX)*2
   - Couplers, coupler pumping line, leak checks (x9)
   - Cabling of flanges A (x8) and flange D
   - Quadrupole current lead connections and welding
   - Final leak check of cavity vacuum (+RGA), final pumping
7. **Shipment Area** (SH-WS) *2
   - Control operations (RF frequency)
   - End-caps closing, N2-insulation
   - CEA-Alsyom “acceptance test” and loading

# module components	# parts manipulated
~ 120	>264
~ 256	>420
~ 3 702	>4 399
~209	>209
Total 9 422	Total >12 400